Life in the Universe: More *E. Coli* than *E.T.*

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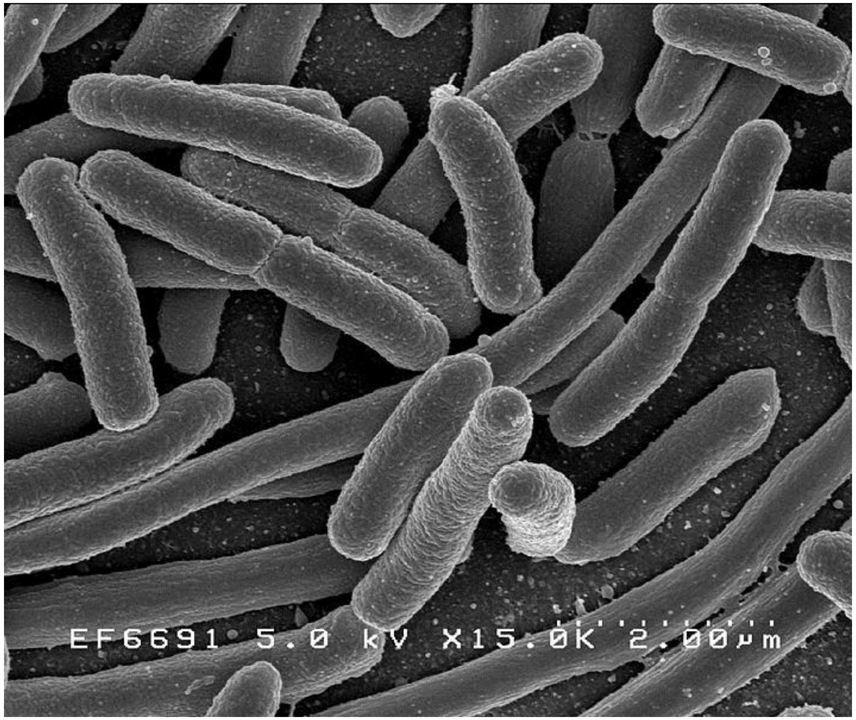
What do aliens look like?



What do aliens look like?

Overview: Searching for life in the Universe

Why?

What?

Where?

How?

Who?

Questions to answer

Why search for life on other planets?

What do we need to look for?

Where should we look?

How do we go about the search?

Who will we find?

Questions to answer

Why search for life on other planets?

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Questions to answer

Why search for life on other planets?

What do we need to look for?

Where should we look?

How do we go about the search?

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A brief history of extra-terrestrial life

- **In Science**
  - As far back as Ancient Greece
  - 16/17th Century: “canals” on Mars
  - 1950s onwards: habitable worlds, active searches
- **In Science Fiction**
  - 17th/18th/19th Century
  - Mass popularity in 1898 with “War of the Worlds” by H. G. Wells.
  - 1970s - today: an explosion of books, movies, and ideas
  - As science advances, SF races ahead!

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Why?

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Why? Monty Python put it best!

"So remember, when you're feeling very small and insecure,
How amazingly unlikely is your birth,
And pray that there's intelligent life somewhere up in space,
'Cause there's bugger all down here on Earth."

'Galaxy Song', from 'Monty Python's The Meaning of Life' (1983)
https://www.youtube.com/watch?v=buqtdpuZxvk

Seriously though, why? Philosophically…

Copernican Principle

- “The Earth does not occupy a ‘special’ or ‘central’ position in the Universe”

Mediocrity Principle

- “If an item is drawn at random from one of several sets or categories, it's likelier to come from the most numerous category than from any one of the less numerous categories”

That doesn't mean life is common!

Probability: Drake equation (Frank Drake, 1961)

- Attempt to quantify the number of civilisations in the Milky Way
- Mainly serves as a method to quantify our ignorance

Fermi Paradox (Enrico Fermi, 1950)

- "Where is everybody?"

Great Filter hypothesis (Robin Hanson, 1996)

- Suggests 9 steps of an evolutionary path, and that at least one of them must be very unlikely, otherwise we'd have met someone else by now

Drake Equation

The Drake equation is a good way to take an educated guess about how many civilisations are out there.

Not particularly scientific, but it gives us an idea!

Drake Equation

$$N = R_* \cdot f_P \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

N = the number of civilizations in our galaxy with which radio-communication might be possible

R_*= average rate of star formation rate in our galaxy

f_P = fraction of those stars that have planets

n_e = the average number of planets that can potentially support life per star that has planets

f_l = the fraction of planets that could support life that actually develop life at some point

f_i = the fraction of planets with life that actually go on to develop intelligent life

f_c = the fraction of civilizations that develop a technology that releases detectable signs of their existence into space

L = the length of time for which such civilizations release detectable signals into space

Drake Equation

Time to get estimating! Have a go at working out N.

Take R_* to be 1 per year.

Remember order-of-magnitude estimates!

Drake Equation

The original estimates made by Drake and his colleagues were:

R_* = 1 per year

f_P = 0.2-0.5 (one fifth to one half of all stars formed will have planets)

n_e = 1-5 (stars with planets will have between 1 and 5 planets capable of developing life)

f_l = 1 (100% of these planets will develop life)

f_i = 1 (100% of which will develop intelligent life)

f_c = 0.1-0.2 (10-20% of which will be able to communicate)

L = 1000-100,000,000 years (which will last somewhere between 1000 and 100,000,000 years)

So $N \approx$ 1000 to 100,000,000 civilisations in the Milky Way

The “Great Filter” evolutionary path

1. The right star system i.e. chemical composition, habitable planets.
2. Reproductive molecules e.g. RNA
3. Simple single-cell life (prokaryotes)
4. Complex single-cell life (eukaryotes and archaea)
5. Sexual reproduction
6. Multi-cell life
7. Tool-using animals with big brains
8. **Where we are now**
9. Colonisation explosion

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At least one of these is unlikely, probably more!

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If this is the most difficult step to reach then we might be in trouble!

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We can search for indirect signs of these three in other solar systems

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9. Colonisation explosion

We may soon be able to search for direct signs of this in our own Solar system!

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What?

What are the conditions necessary for life*?

* As we know it!

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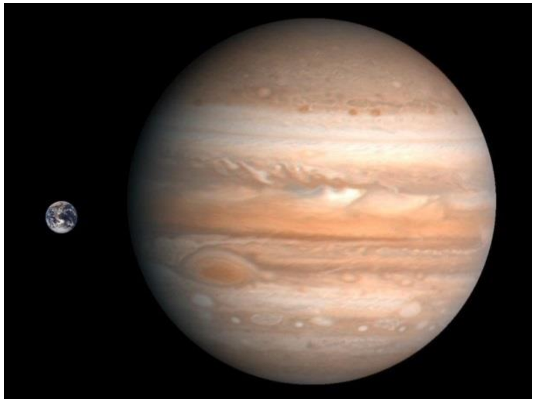
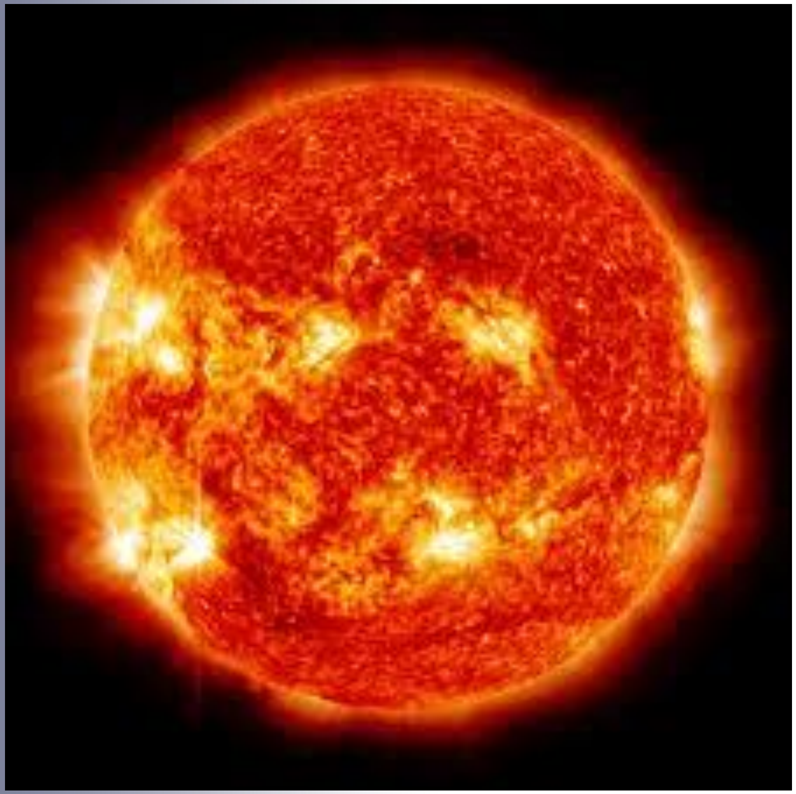
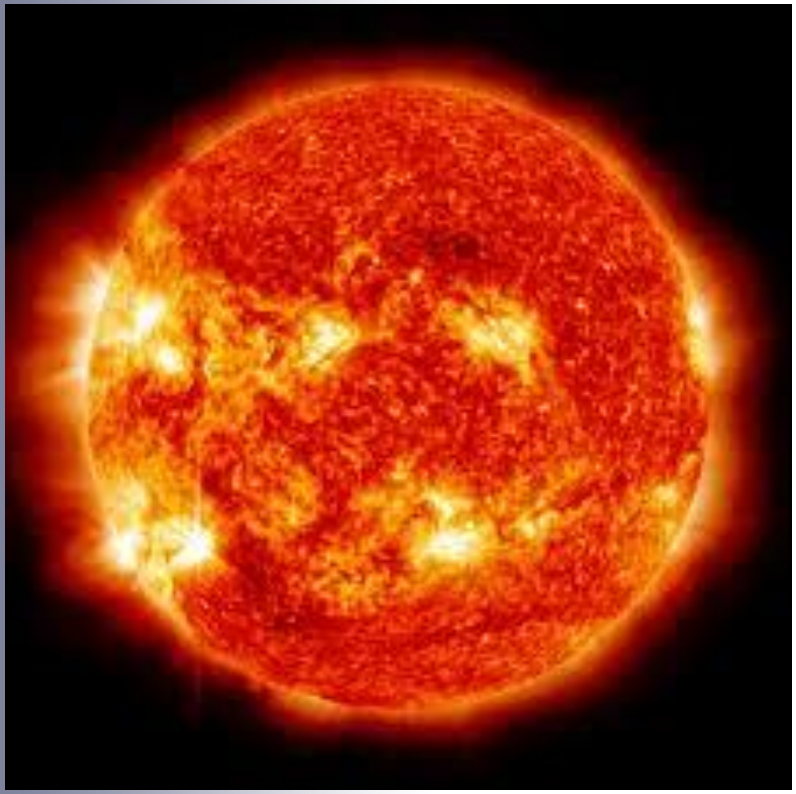


* As we know it!

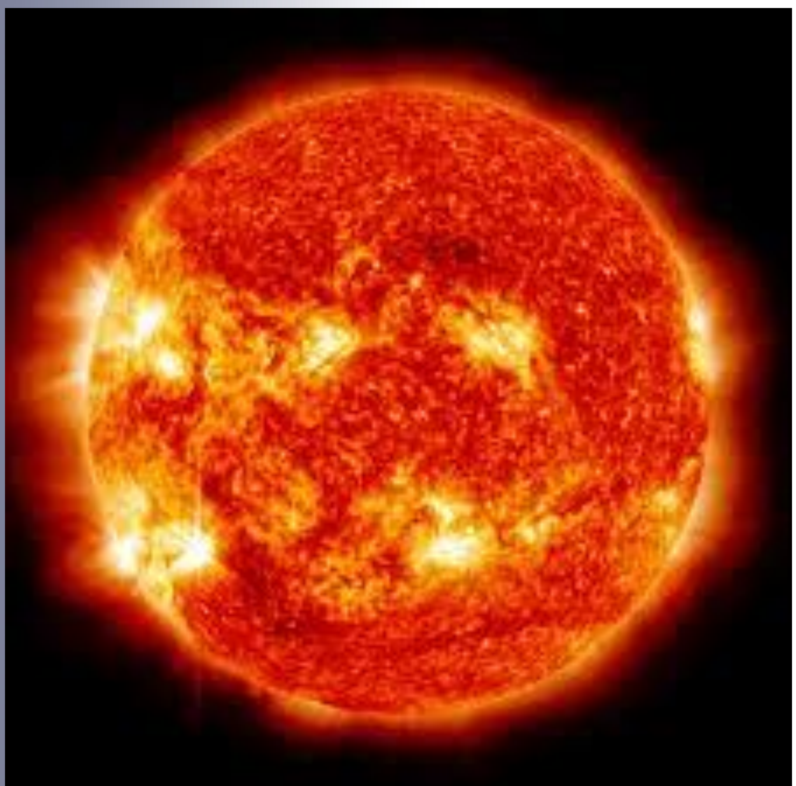
Sun?



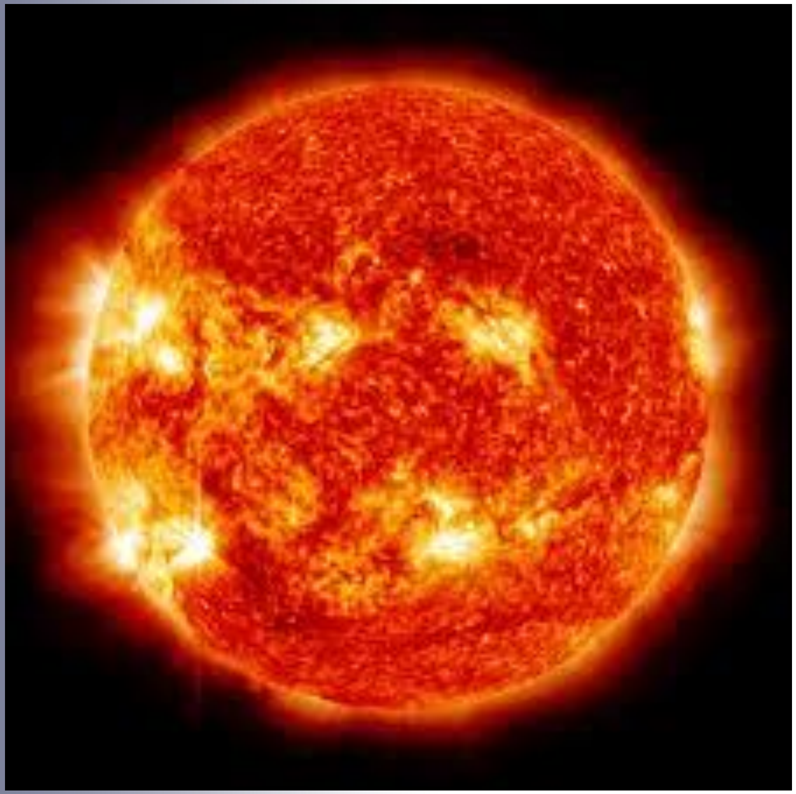
Solar energy

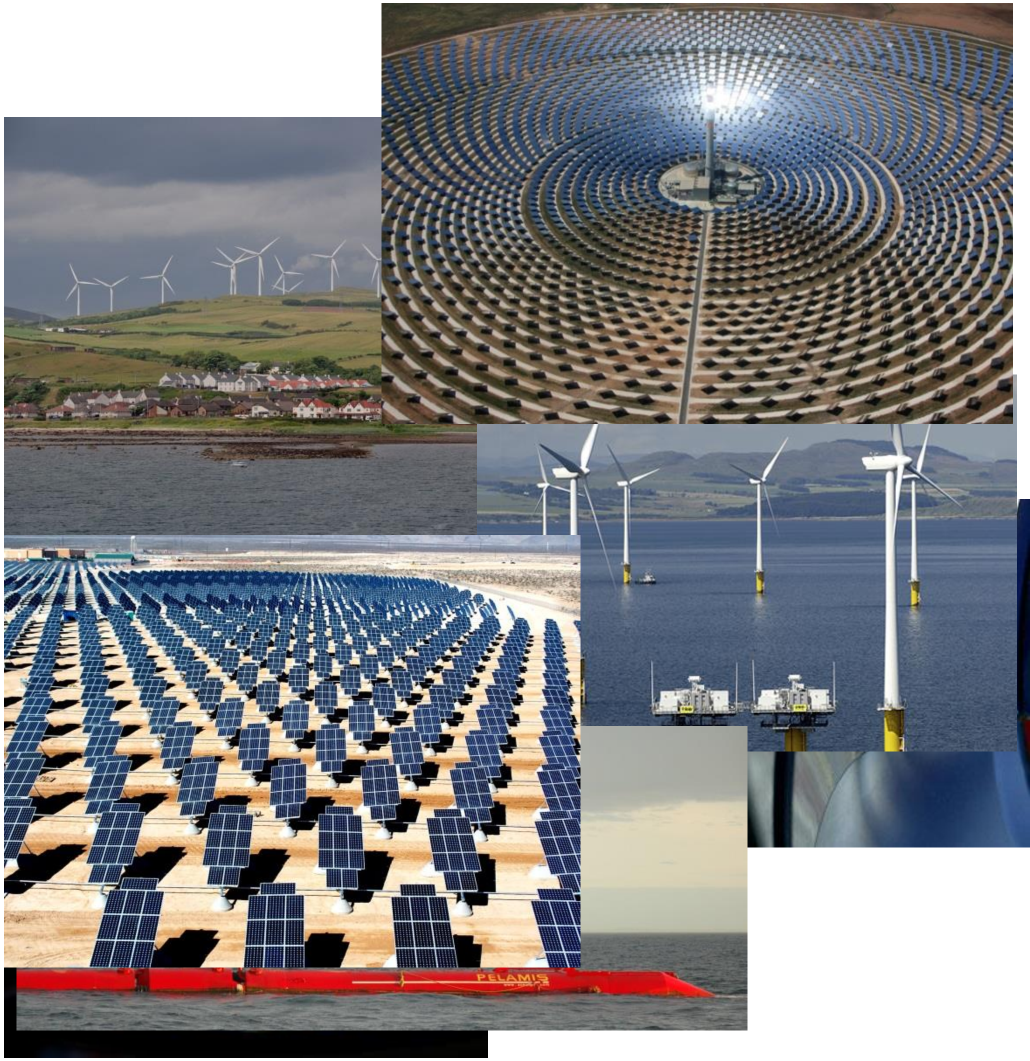


Solar energy



Solar energy





Water?

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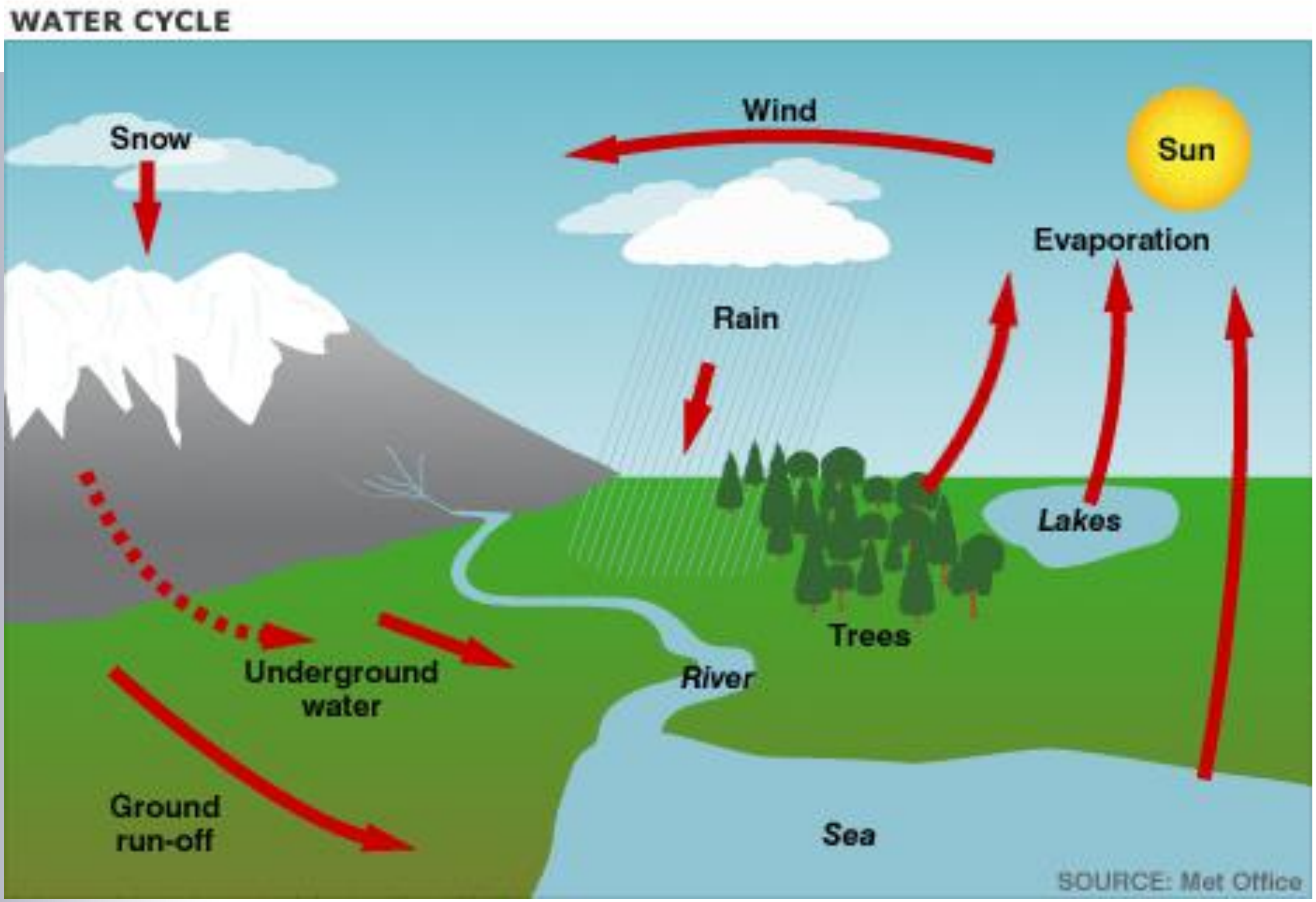
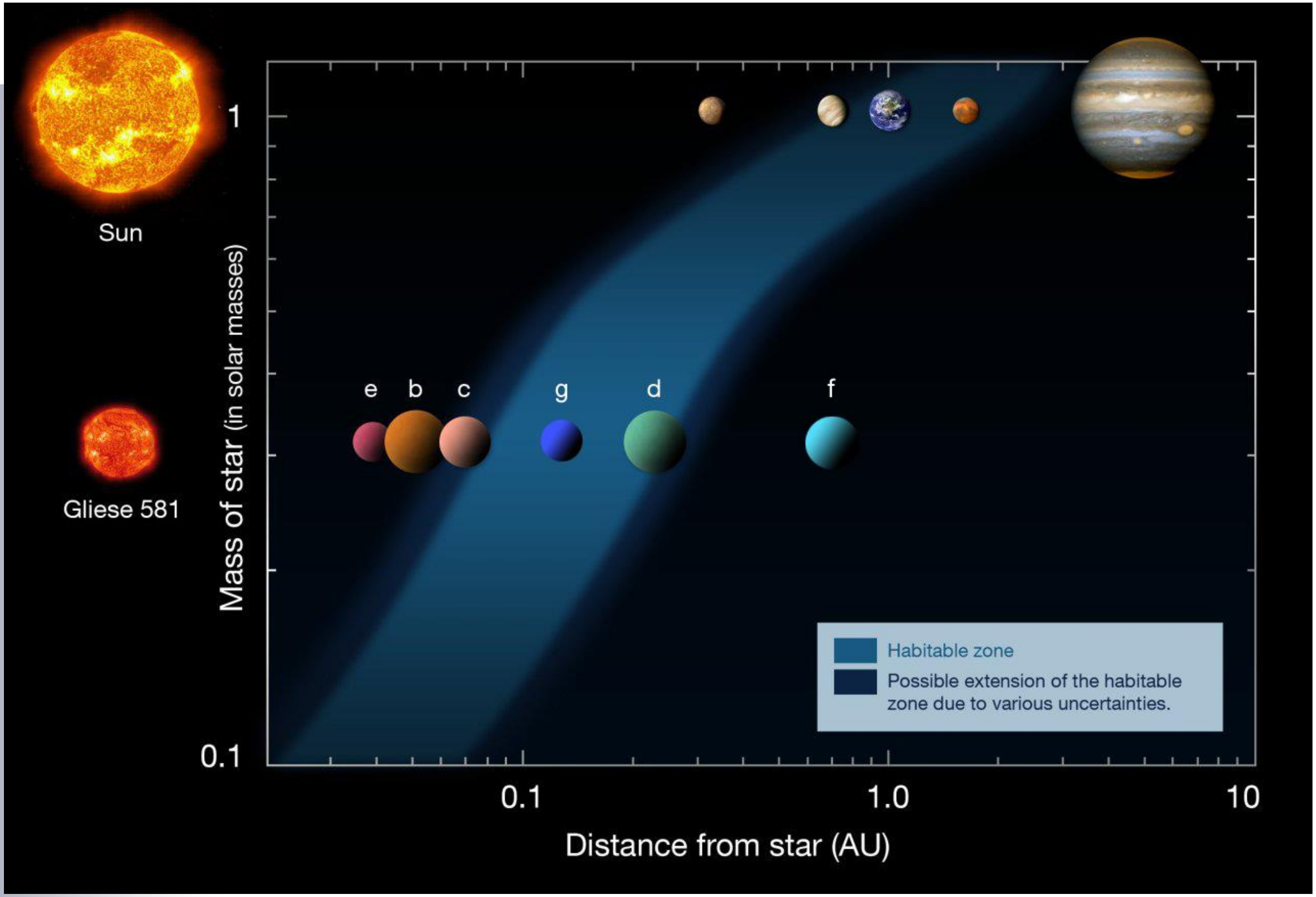
Water?

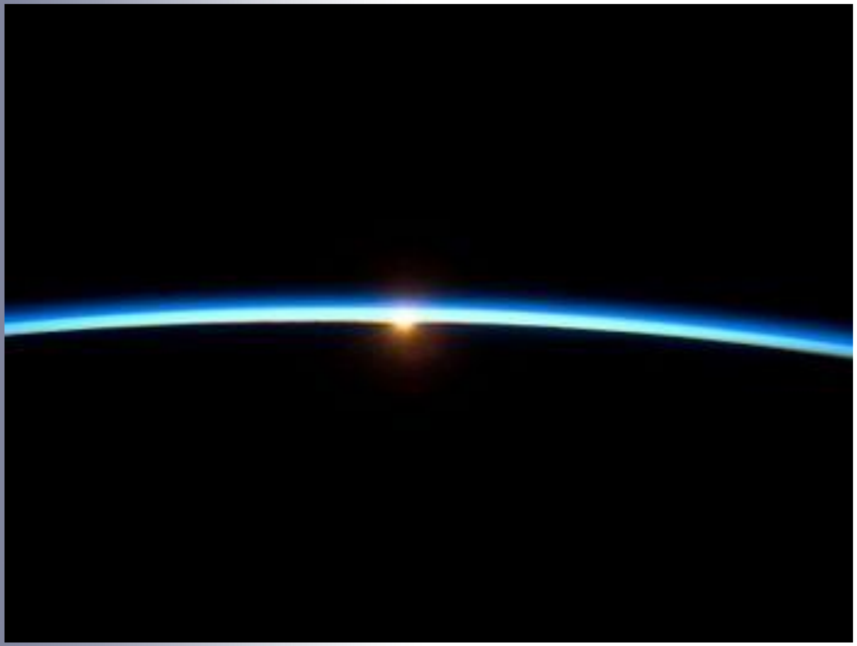
Three phases of water

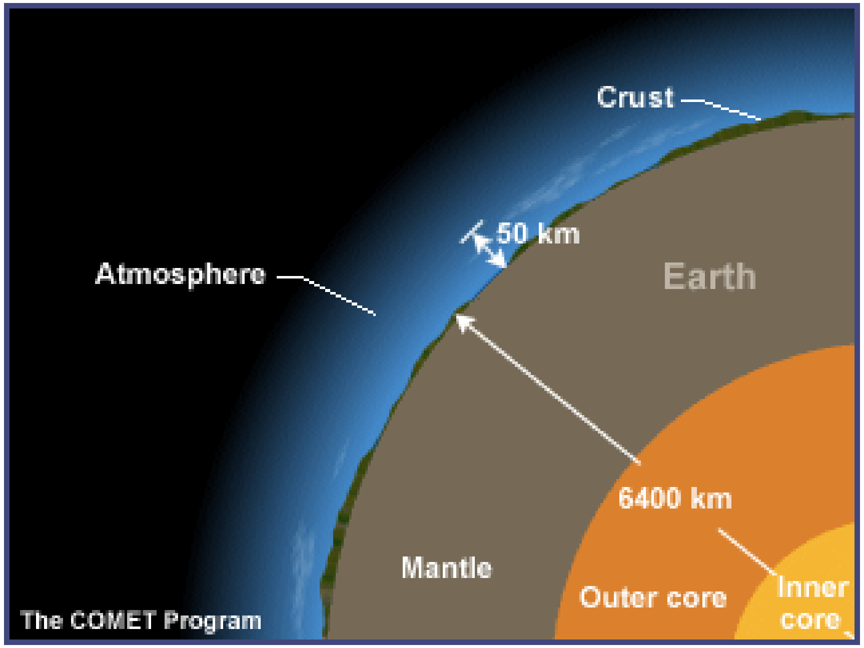


“Goldilocks Zone”

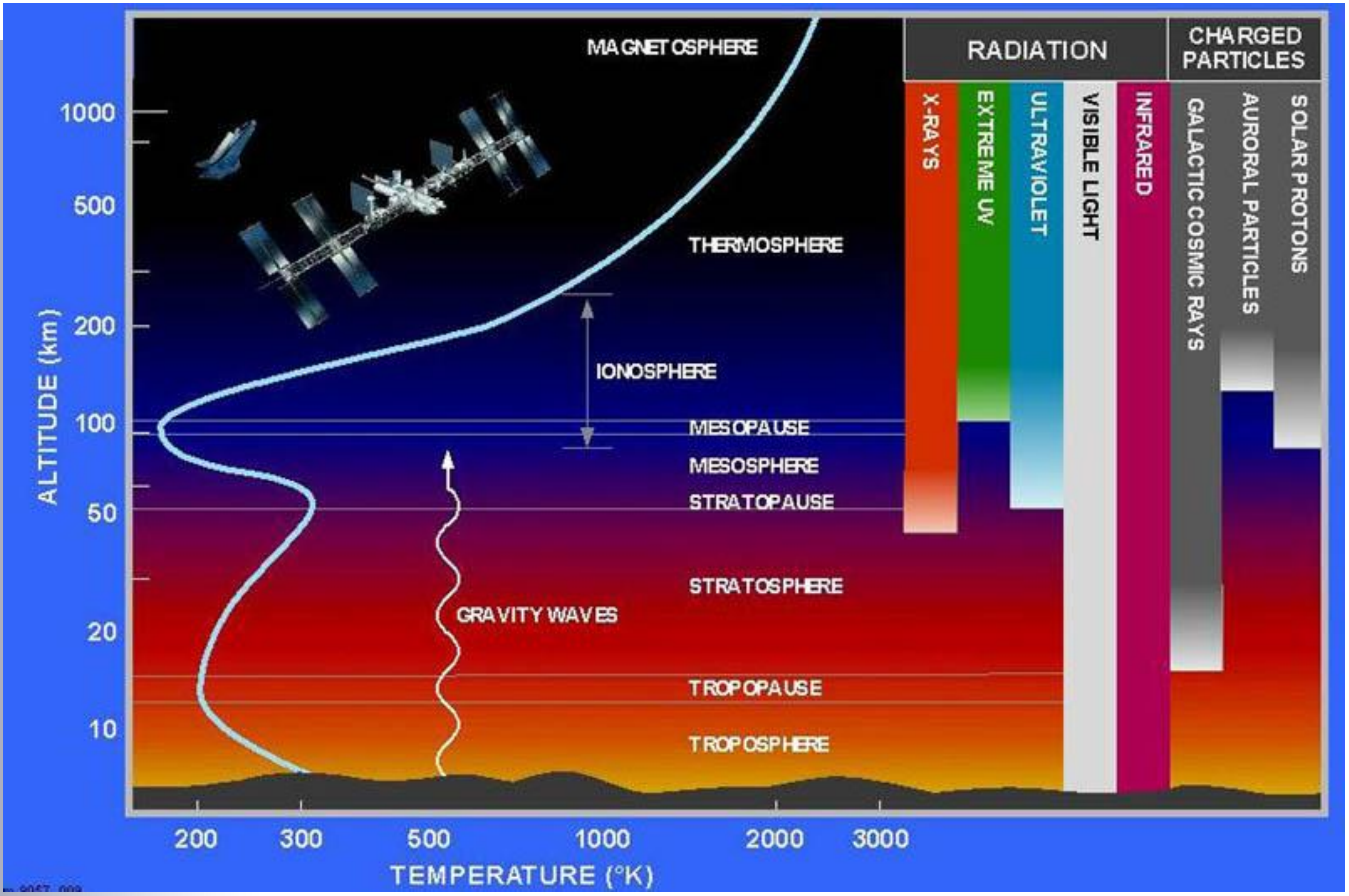


Atmosphere: A thin protective shell

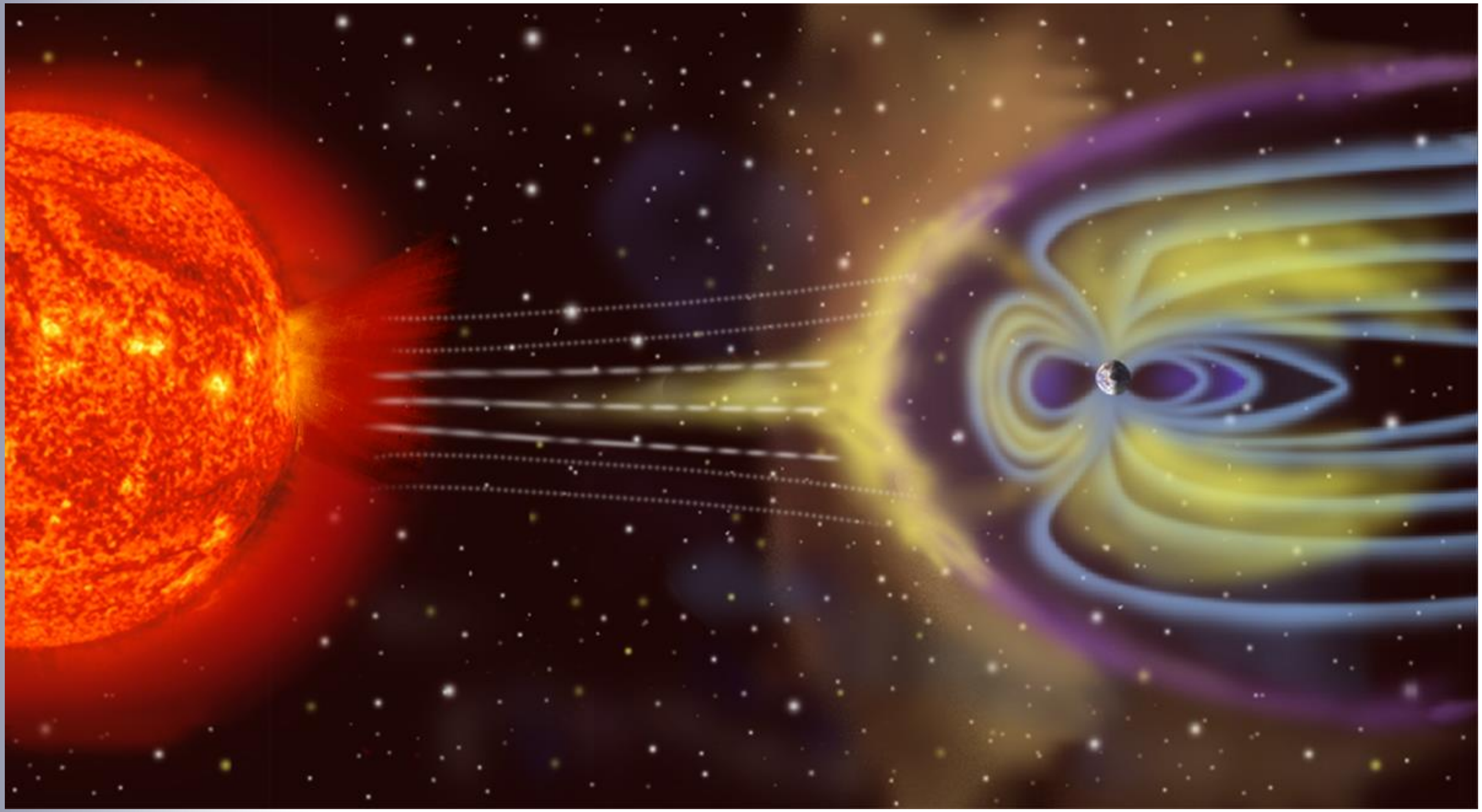




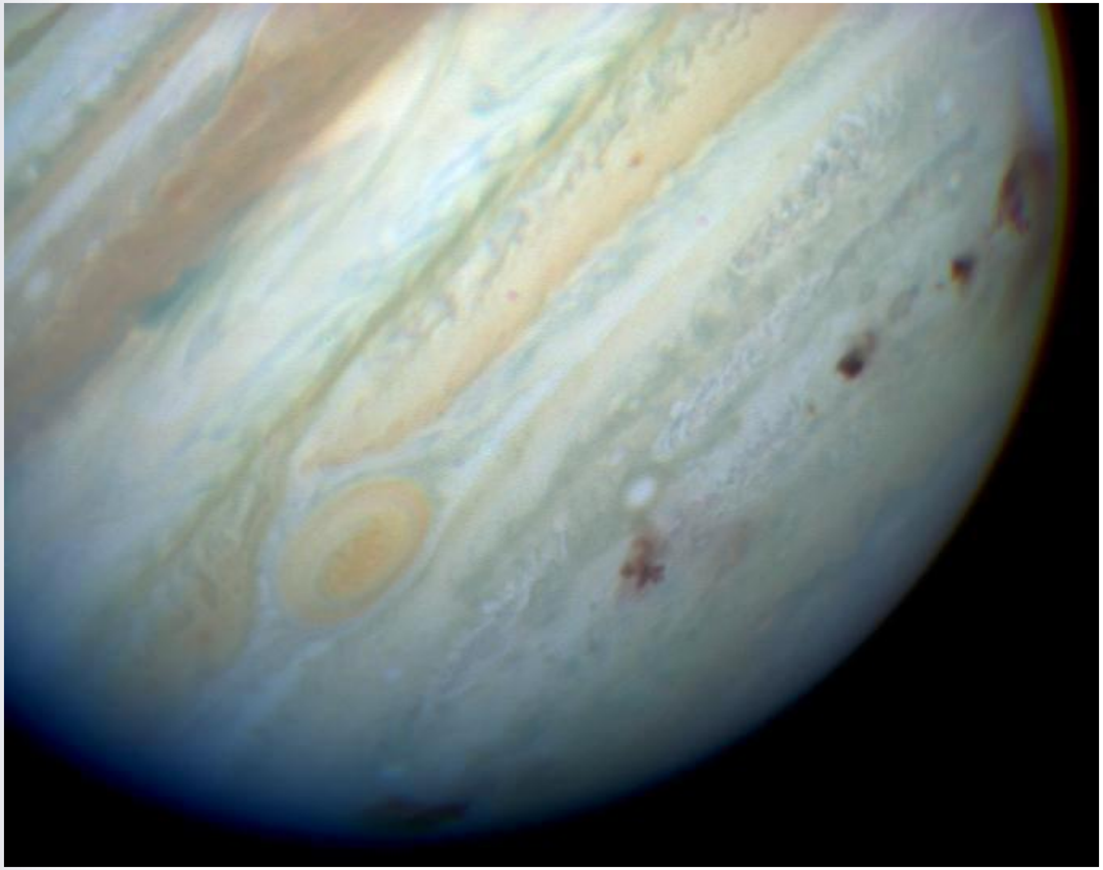
Atmospheric layers



Magnetosphere?



“Big brother” planet?



Total solar eclipses?

Neat shorthand for a number of factors:

- Habitable zone
- Tides (possibly needed for complex life)
- Extra asteroid protection
- All in just the right proportion!

Where?

Two places to look

- **Within our solar system**
  - Direct searching with probes etc
  - Includes planets, moons, comets, and asteroids
- **Outwith our solar system (exoplanets)**
  - Indirect searching
  - Step 1: find Earthlike planets

How?

Direct Searches?


Extent of Human
Radio Broadcasts
200 light years in diameter
Thanks to Nick Risinger for the artist's conception of the Milky Way.
Taken from http://commons.wikimedia.org/wiki/File:Milky_Way_Galaxy.jpg

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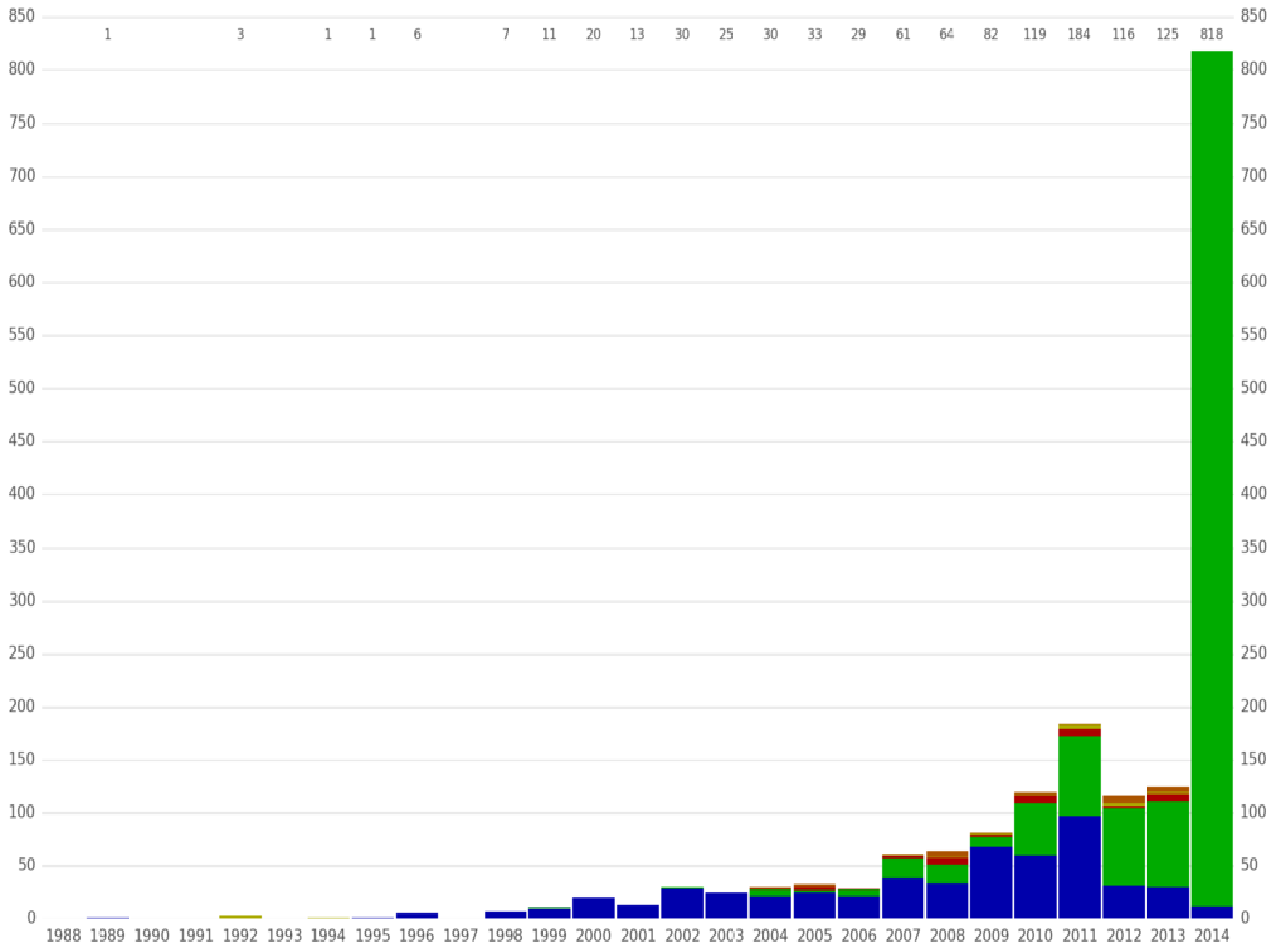
We can't just go there like in the movies… yet…

Methods of detecting exoplanets

- Direct imaging
- Gravitational Microlensing
- Pulsar timing
- Doppler Method
- Transit Method

Exoplanet discovery methods



Blue – Doppler Method

Green – Transit Method

Red – Direct Imaging

Yellow – Pulsar timing

Orange - Microlensing

Methods of detecting exoplanets

Direct Imaging

- Very challenging!
- Parent star is very bright in comparison to the planet.
- Only planets that have been imaged this way have been very massive with a large orbital radius.

Methods of detecting exoplanets

Gravitational Microlensing

- Microlensing occurs when the gravitational field of a star acts as a lens magnifying distant objects.
- If a planet is orbiting the lensing star then it causes anomalies in the magnification over time.
- This method is most sensitive to planets within 1AU – 10 AU of the parent star.

Methods of detecting exoplanets

Pulsar Timing

- A pulsar is the very dense remnants of a supernova. They give out very regular pulses of radio waves.
- If a planet is orbiting the pulsar it causes small abnormalities in the timings of the pulses of radiation.
- A very situational technique, but gives very precise results.

Methods of detecting exoplanets

Doppler Method

- As a planet orbits around the parent star the star also experiences motion as the two objects are actually orbiting around a centre of mass.
- The changes in the speed of which the star is moving towards us and away from us can be seen by the Doppler effect.
- When the star is moving away from us the light it is emitting is stretched, and is redshifted.
- Light is blueshifted when the star is moving towards us.
- By analysing these changes in wavelength we can determine if there is a planet present and measure a lower limit to its mass.

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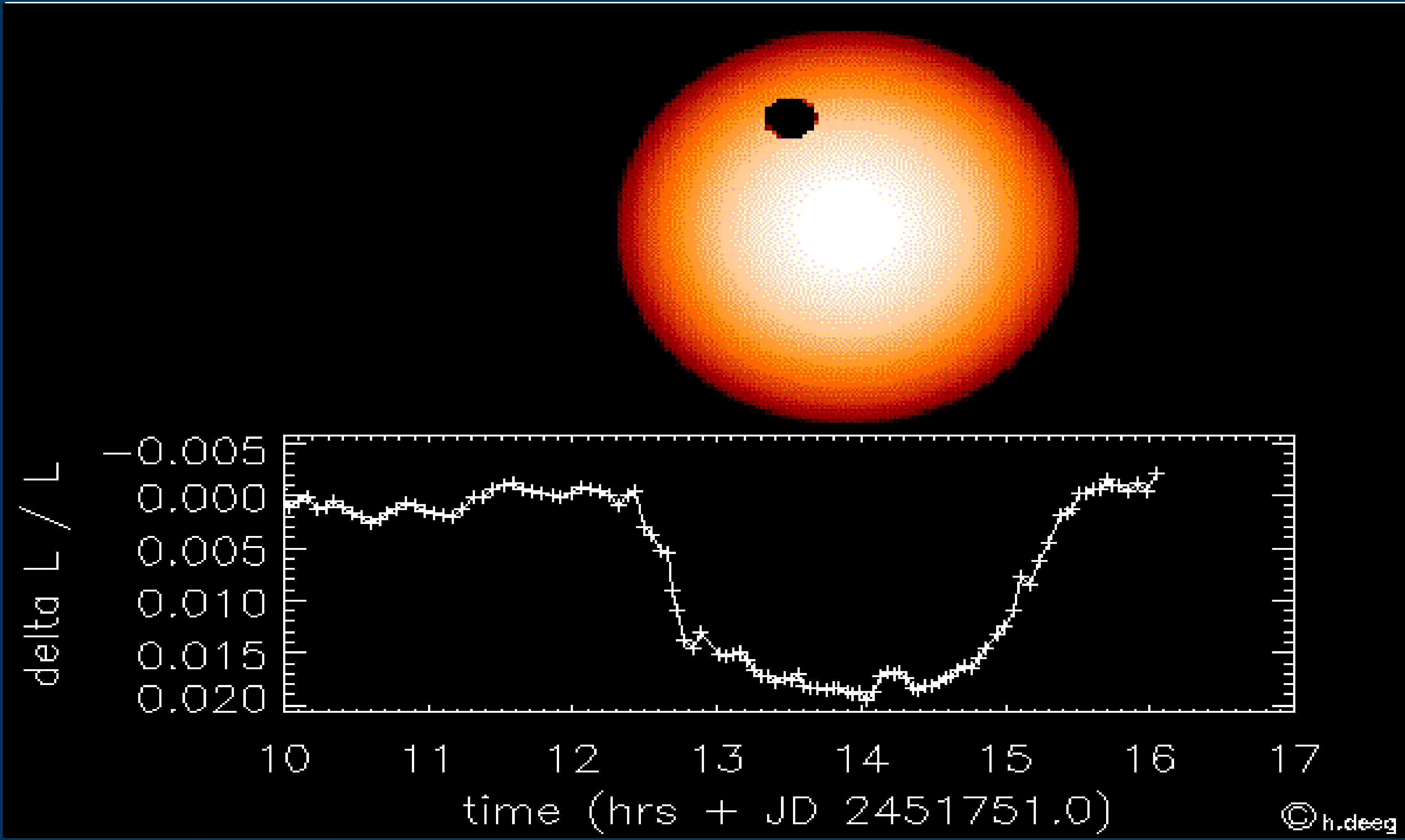
Methods of detecting exoplanets

Transit Method

- When a planet orbits around its parent star it will cross the star's disk.
- By observing the brightness of a stars disk we can see periodic drops in the brightness when the planet moves in front of the star.
- This method reveals the planet's radius. We can also use spectroscopy to study the planet's atmosphere.

The transit method is by far the most successful method for detecting extra solar planets.

Light Curve



delta L / L
-0.005
0.000
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time (hrs + JD 2451751.0)
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Extra-solar planets

- First one discovered in 1992 (PSR B1257+12)
- First Main Sequence system in 1995 (51 Pegasi)
- In 2007, about 130 known
- **As of 20th November 2014, 1850 confirmed planets in 1160 systems, including 472 multiple planet systems**
- Discovery rate is extremely rapid – in February this year the numbers were 1077 planets in 814 systems, and 179 multiple planet systems.

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- Discovery rate is extremely rapid – in February this year the numbers were 1077 planets in 814 systems, and 179 multiple planet systems.
- **On average we expect to find one planet per star**
- **One in five Sun-like stars have an Earth-sized planet in their habitable zone (about 11 billion planets)**

Extreme Exoplanets

- Least massive: twice the mass of the Moon (PSR B1257+12A)
- **Most massive: 29 times the mass of Jupiter (should probably be categorised as a Brown Dwarf)**
- Nearest: 4.37 light years (Alpha Centauri Bb – 1.1 times the size of Earth)
- Farthest: 21,500 ± 3,300 light years (OGLE-2005-BLG-390Lb)
  - Microlensing event PA-99-N2 suggests a planet orbiting a star in the Andromeda Galaxy (~2.5 million light years away)

Kepler mission

- Launched in 2009
- Searches by transit method
- Planets passing in front of stars cause a slight dip in brightness (see transit experiment on Friday)
- As of June 2014, 977 confirmed planets detected
- Plus a further 3277 candidate planets unconfirmed

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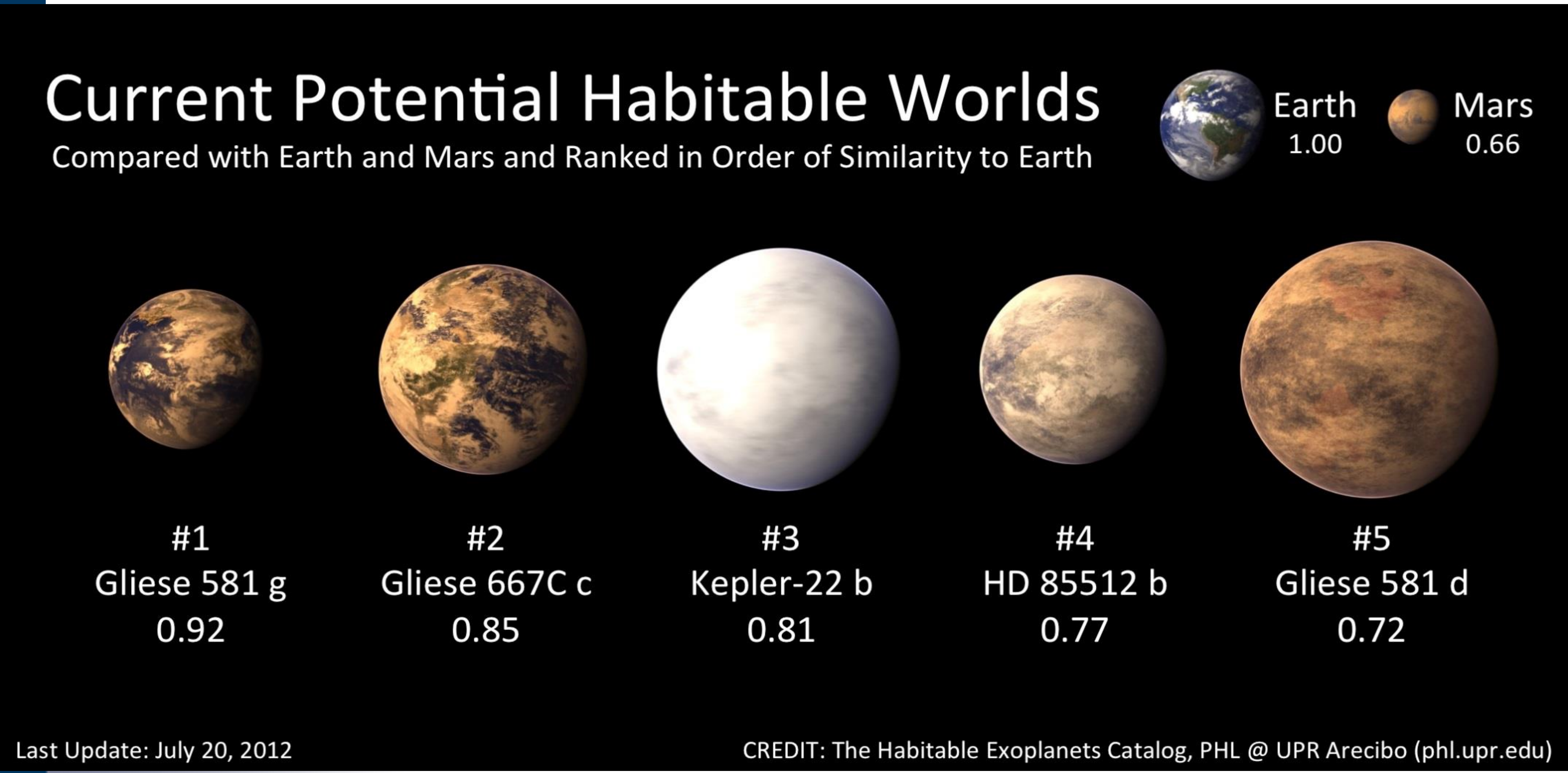
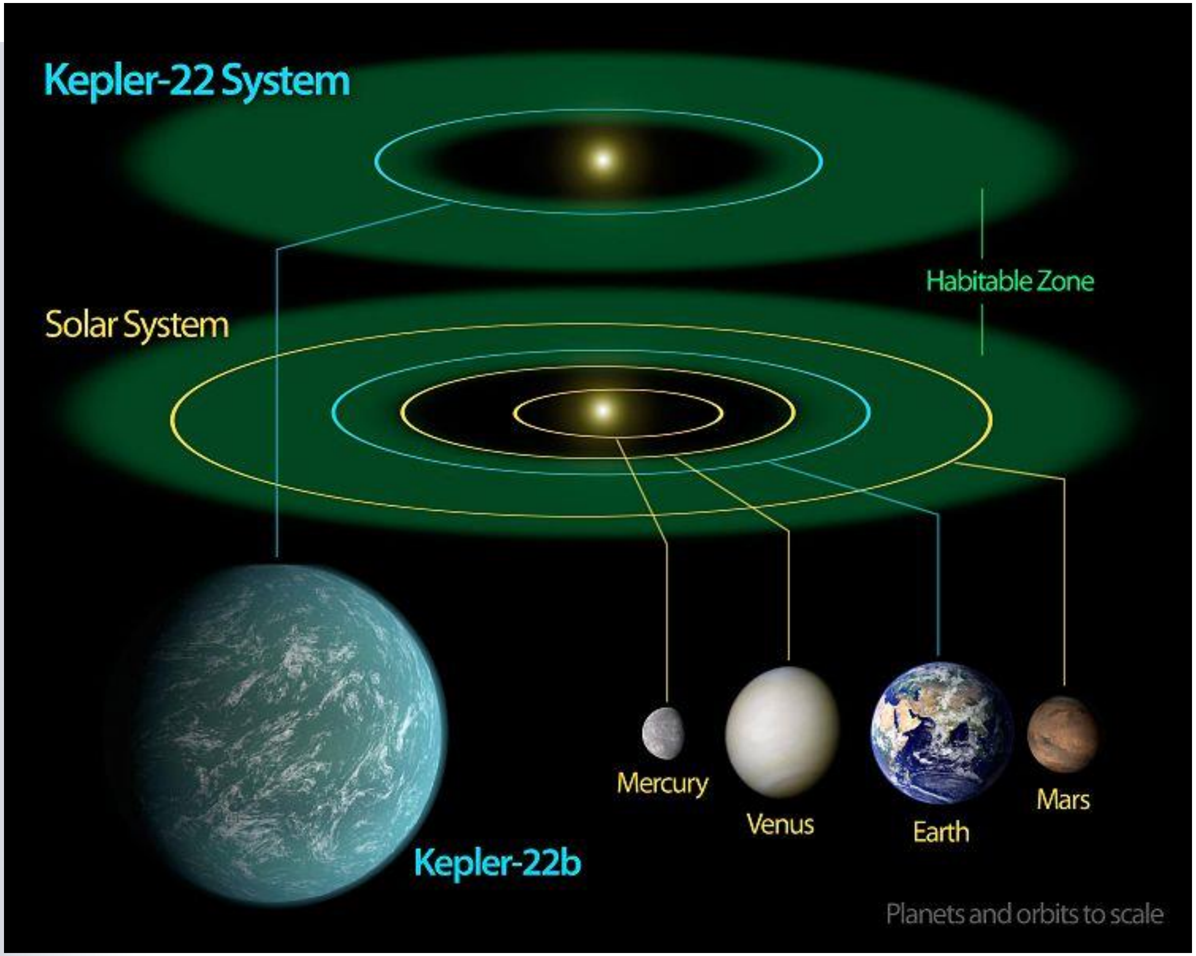


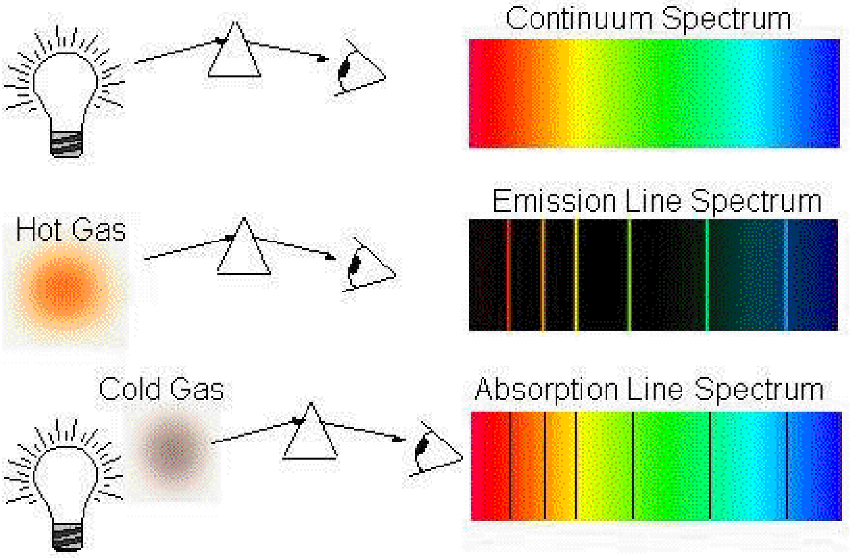
First confirmed habitable zone planet! (2011)



2.4 times the size of Earth

Searching for evidence of life

- Transiting planets will absorb some light from their star
- Element and compound “fingerprints” can be detected this way
- See ‘Spectroscopy’ next Wednesday.



Which substances should we look for?

- Studying the planetary atmosphere
- Presence of Oxygen might indicate plants/trees
- Presence of Methane might indicate animals
- Polycyclic aromatic Hydrocarbons (PAH) thought to be building blocks of life
- Finding water would also be handy!

- Feb 2014: 50 transiting, 5 directly imaged atmospheres studied
- Spectroscopy and polarimetry used to study the atmospheres

Exciting results?

Yes!

- HD189733B: Water, CO, CO_2, Methane detected (2008)
- Five planets have water in their atmospheres (2013)
- Kepler 7-b: Clouds in the atmosphere (Oct 2013)
  - Also shown in Dec 2013 for GJ436b and GJ1214b

Other worlds in our solar system

- Mars
- Europa
- Titan
- Comets (panspermia)

- So how can we search these worlds for life?

Other worlds in our solar system

- Mars
- Europa
- Titan
- Comets (panspermia)

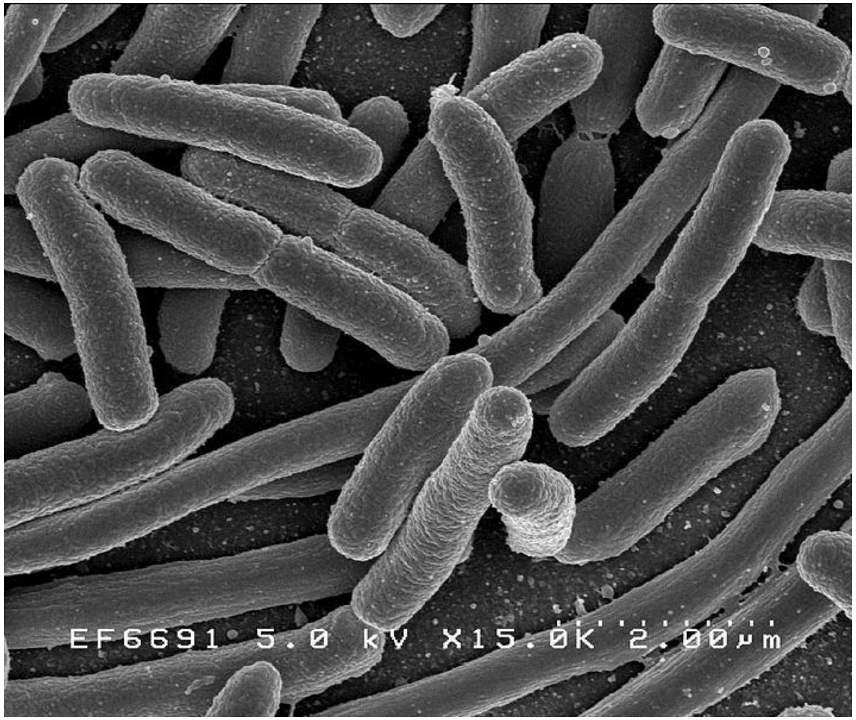
- So how can we search these worlds for life?

That depends on who we are looking for…

Who?

Simple life

- Bacteria are remarkably resistant to heat, cold, radiation, acid, pressure…
- Living bacteria have been found in very extreme conditions on Earth



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"Extremophile" Bacteria and Archaea

- In hot springs
- At volcanic vents deep under the ocean
- In permafrost
- Spores in pharaoh's tombs still viable after 3000 years
- Claims of viable spores 40 million years old!

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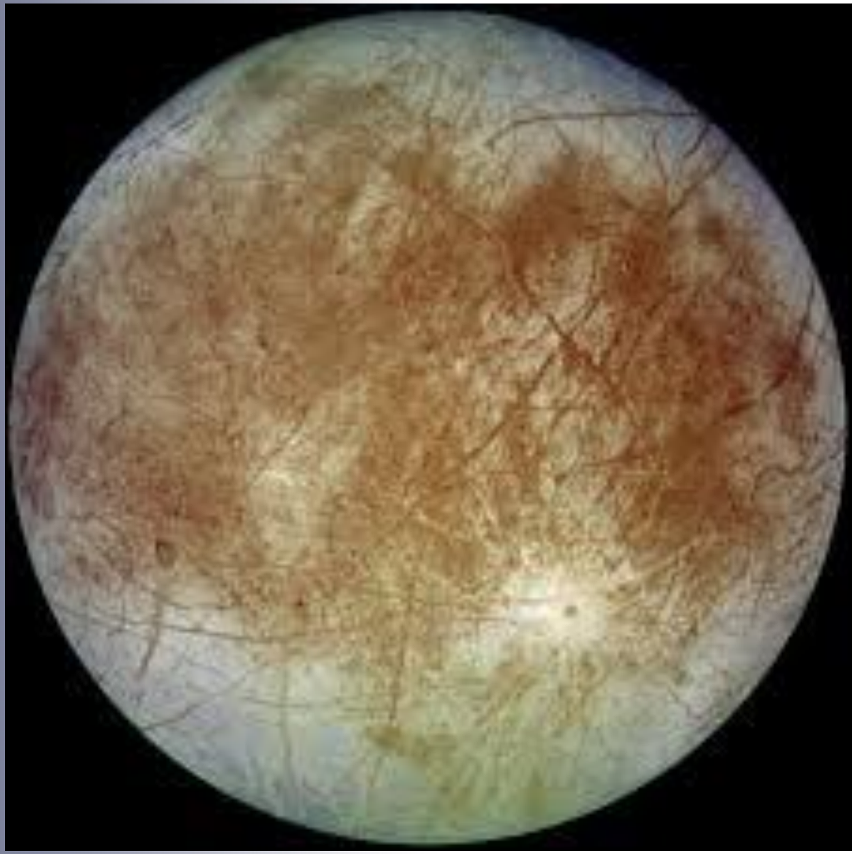
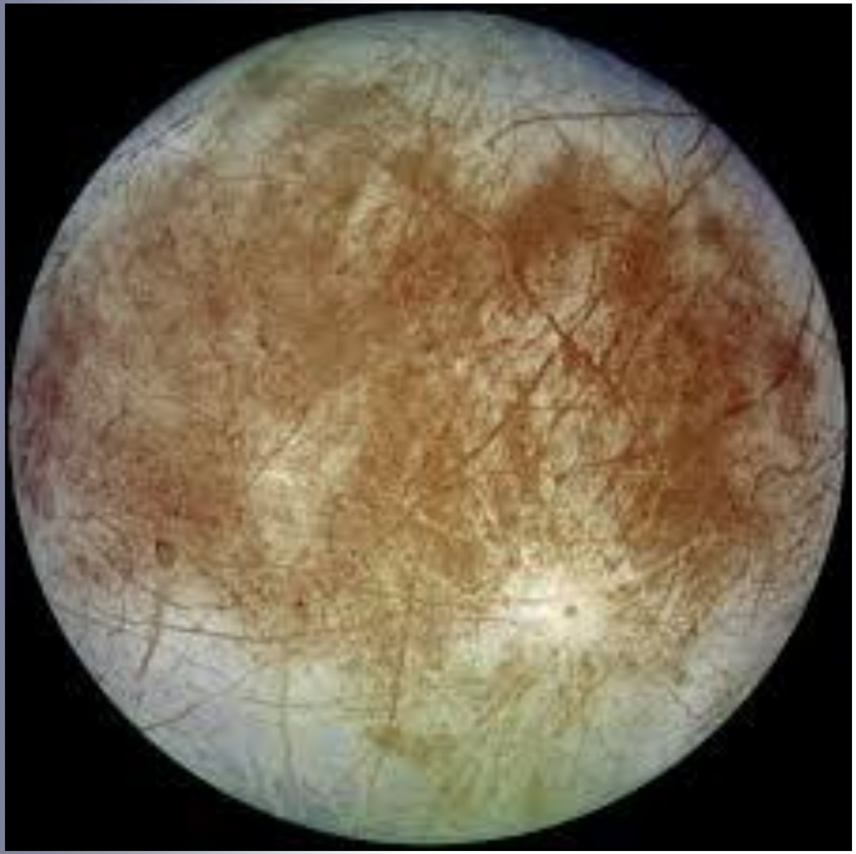
Life has been found on Earth in diverse environments

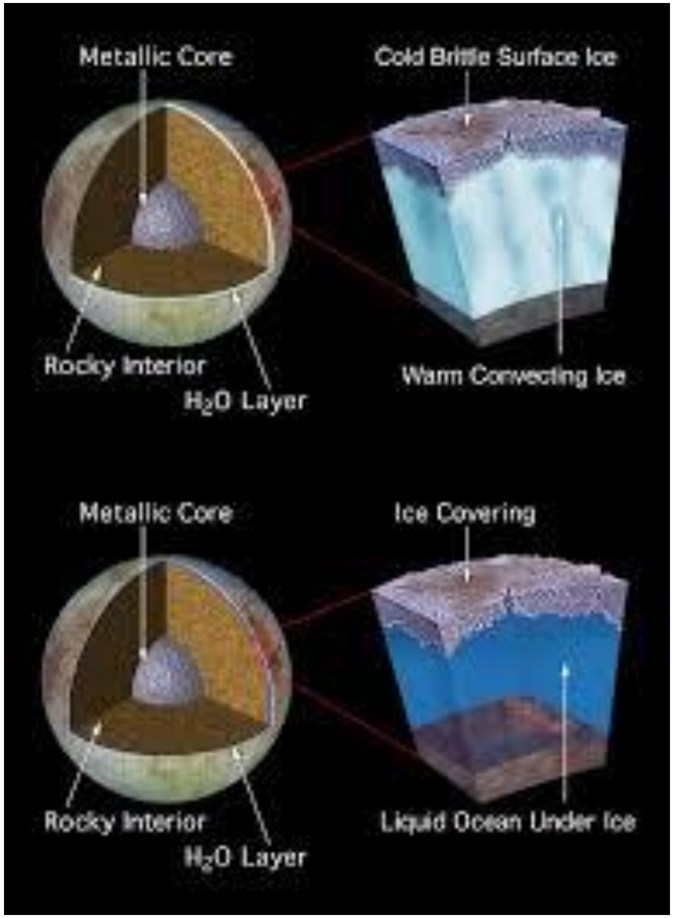
- Highly acidic ($pH < 3$)
- Highly alkaline ($pH > 9$)
- In high-salt or high-sugar environments
- In temperatures < -15 ^oC and > 120 ^oC
- In microscopic pores in rocks
- In very dry conditions
- At very high pressure e.g. deep underwater
- Some are very resistant to radiation
- **Some require/enjoy *several* extremes!**

Case study: Europa



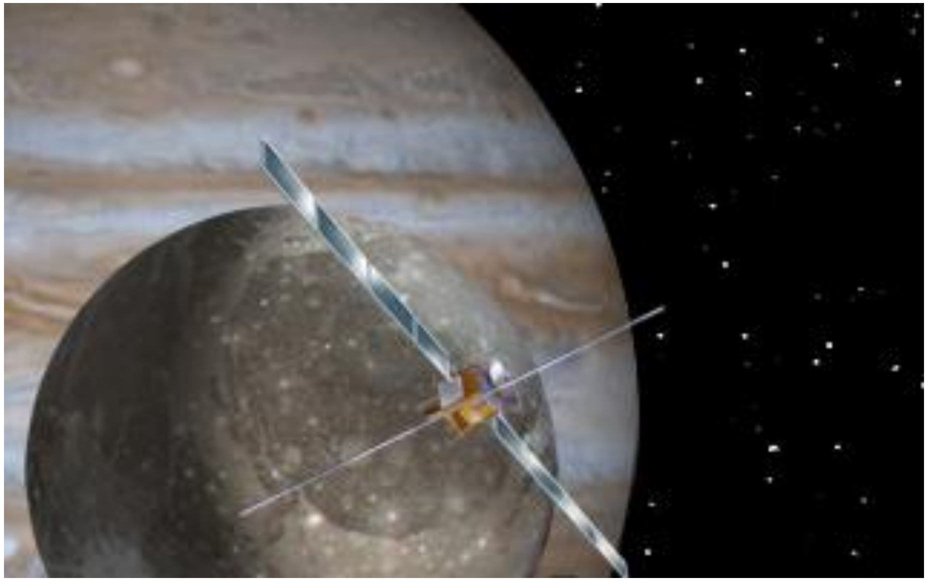
Case study: Europa



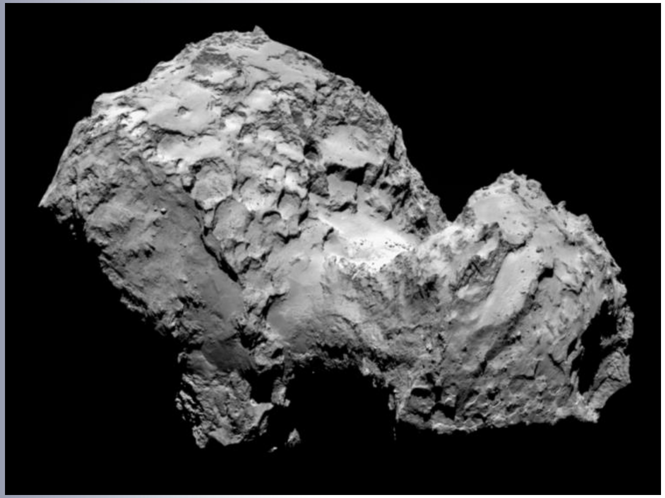


Europa

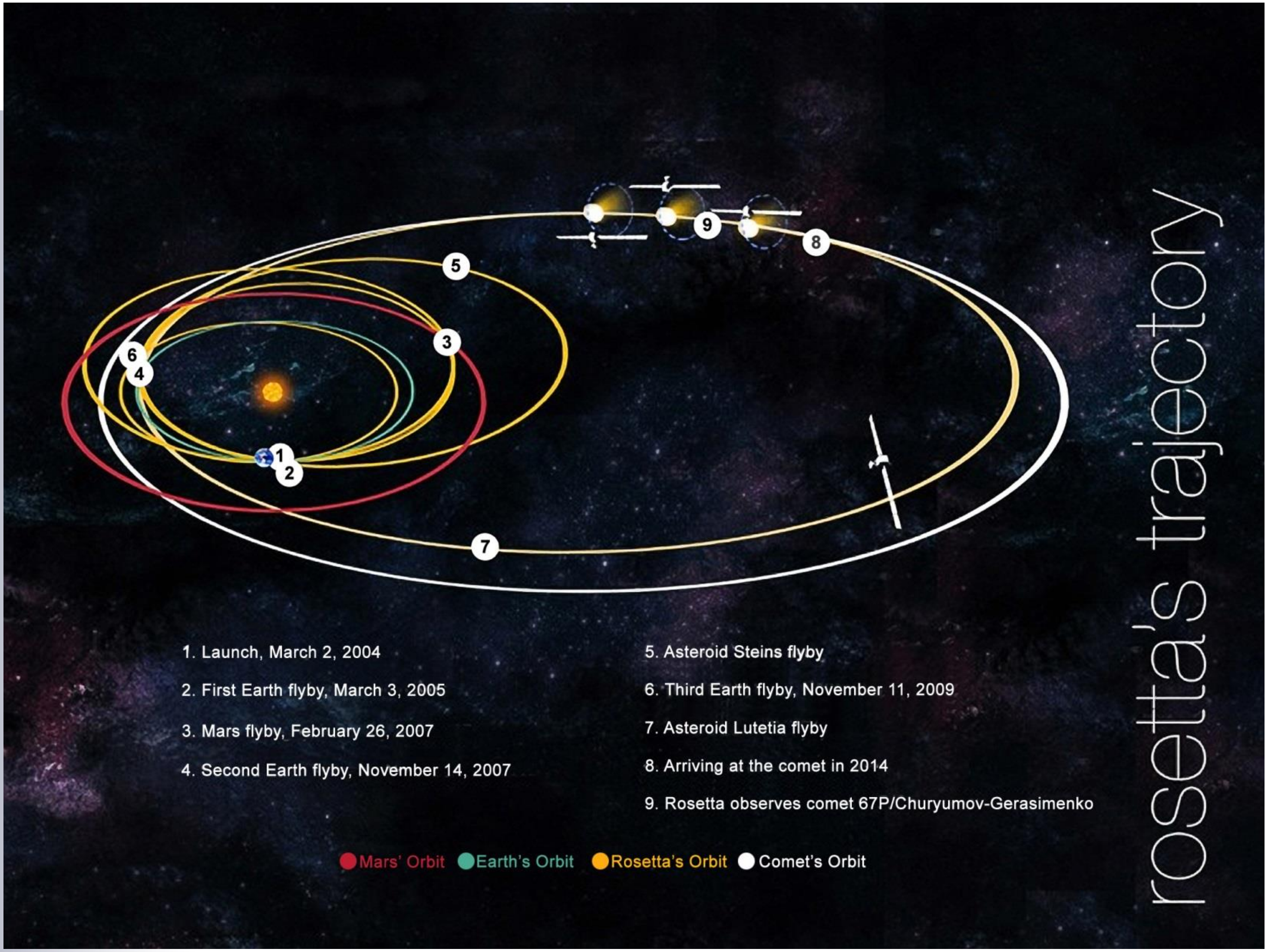
- Smooth icy surface indicates liquid water underneath
- Tidal heating similar to plate tectonics
- December 2013: Phyllosilicates discovered
- JUICE mission planned by ESA for 2022 – two flybys, not landing



Case study: Comet 67P

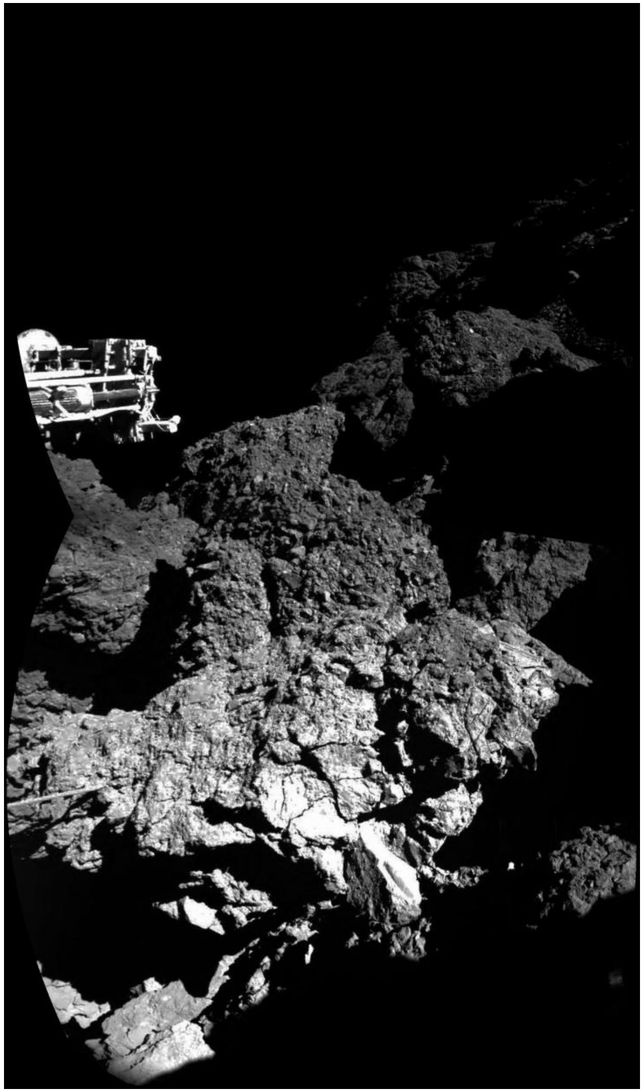


Case study: Comet 67P



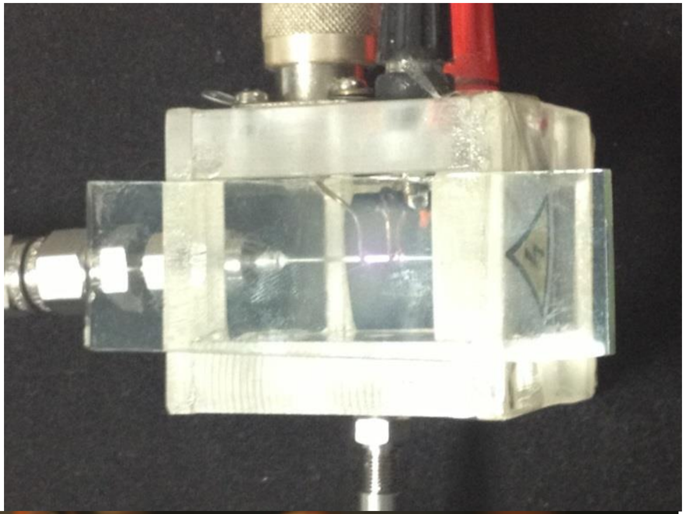
What did Philae find?

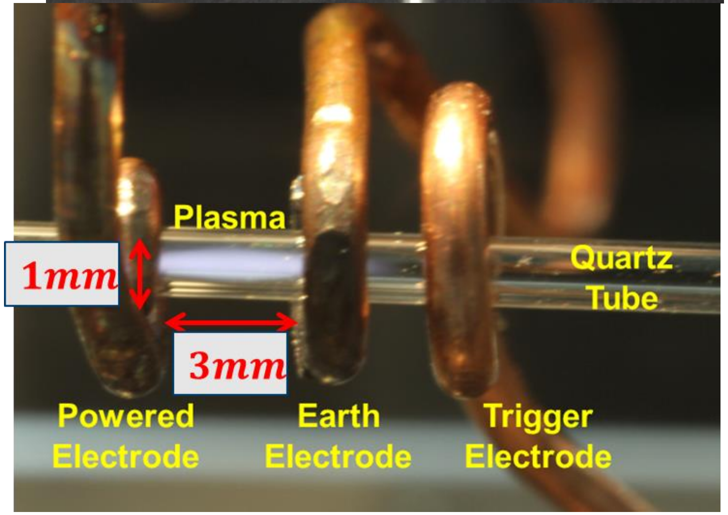
- Over 2 days of study before batteries ran out
- May be reawakened closer to the Sun
- Lots of data currently being analysed
- BUT organic molecules discovered!
- Building blocks of life?



So how about direct detection of life?

- Microplasma device delivers electric charge onto cells
- Different species are different sizes and shapes
- Electrostatic trap should distinguish between species (after calibration)
- Applications in hospitals, swimming pools, airports, kitchens…
- …and spacecraft!





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Thanks for your attention!

Any questions?